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Safety and efficacy of short-term ventricular assist devices in paediatric heart transplant candidates: a systematic review and single arm meta-analysis

Nathanael Q.E. Yap[1*], Joseph Nasr[2], Shahid Miangul[3], Liranne Bitton[4], Suresh Z. Seneviratne[5,6], Armin Farzad[7], Jenase F. Emil-Inyang[4], Maya L. Nasser[8], Shayndhan Sivanathan[9], Christian A. Than[1,10] and James W. F. Burns[11]

Abstract

Background Safety and efficacy of short-term ventricular assist devices (VAD) remains incompletely understood, particularly in younger children. This systematic review and meta-analysis aims to evaluate outcomes, including bridging success, complications, and mortality, associated with short-term VAD support in paediatric heart transplant candidates.

Methods A systematic search of PubMed, EMBASE, CINAHL, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Scopus, and Web of Science was conducted from inception to 2 December 2024. Eligible studies reported patients ≤ 18 years supported by short-term VADs. This review was registered in PROSPERO (ID: CRD42023468125).

Results Twelve retrospective studies met the inclusion criteria, encompassing 532 paediatric patients (mean age 10.0 years, < 0.1–18.3, mean weight 39.5 ± 30.3 kg). Pooled proportions show that with a mean support duration of 15.2 days, 50.7% were successfully bridged to transplant (95% CI 36.4%, 65.0%; $I^2 = 91.1\%$) with a 24.8% waitlist mortality (95% CI 17.6%, 31.9%; $I^2 = 63.8\%$), 14.0% (95% CI 7.2%, 20.9%; $I^2 = 97.5\%$) weaned off support and 5.4% (95% CI 2.6%, 8.3%; $I^2 = 39.1\%$) remaining on support. Complication rates were high with haemorrhage (38.9%), renal impairment (35.2%), cerebrovascular events (29.5%), infection (17.8%), and thromboembolism (9.9%) being the most reported.

Conclusions Short-term VADs offer a feasible bridge to transplant in paediatric patients, with success rates comparable to registry data. However, high rates of serious complications and waitlist mortality persist, particularly in these younger children. These findings demonstrate the need for improved patient selection, standardized outcome reporting, and development of safer, size-appropriate devices for paediatric use.

Keywords Ventricular assist devices, Paediatric, Heart failure, Heart transplant

*Correspondence:
Nathanael Q.E. Yap
dr.nathanaelyap@gmail.com

Full list of author information is available at the end of the article

Introduction

The use of Ventricular Assist Devices (VAD) has become increasingly important in paediatric cardiac care, particularly as a means of bridging patients to heart transplantation or recovery. With the demand for donor heart far exceeding supply, mechanical circulatory support offer a critical lifeline for children facing cardiac failure [1]. Short-term VADs, designed for support over days to weeks, are typically employed in the inpatient setting to stabilise critically ill patients. They may serve as a bridge to recovery, an interim solution to long-term devices or eventual transplantation [2, 3]. In adults, short and long-term VADs are well-established, with bridge-to-transplant rates in the range 50–99% depending on policy and donor availability [3–7].

Current usage trends show a dramatic rise in paediatric VAD utilization. According to the Scientific Registry of Transplant Recipients (SRTR), VAD utilisation has increased from 1.1% in the early 2000s to 17.9% in recent years, with 37.7% of paediatric heart transplant recipients in 2022 bridged with VADs [1]. This increase is also accompanied by a decrease in the mean age of VAD-supported patients, reflecting greater availability of smaller devices that have enabled VAD implantation in younger children with congenital heart issues [8]. This is reflected with the use of PediMACs (Pediatric Interagency Registry for Mechanically Assisted Circulatory Support) continuous flow devices, in which the mean age decreased from 3.9 ± 5.2 years (2012–2017) to 3.1 ± 4.5 years (2012–2021) [9, 10].

Outcomes on paediatric VAD use is less established, with access to limited data especially for short-term VAD devices. Historically, the primary mechanical support used has been extracorporeal membrane oxygenation (ECMO). However, its prolonged recovery times requiring intubation and sedation have shifted focus to VADs, which offer longer support and better optimization before transplant [11, 12].

Waitlist mortality has declined significantly for all patients, from 20.8 deaths per 100 patient-years in 2011 to 10 in 2022, largely due to refined patient selection and increased use of VAD. Despite this progress, significant challenges remain for high-risk groups such as paediatric patients with congenital heart disease (CHD) [1]. Although previous meta-analyses have examined complications associated with paediatrics VAD use, such as stroke and bleeding, none have specifically investigated transplant outcomes following short-term VADs [13].

To our knowledge, this is the first meta-analysis to assess the safety and efficacy of short-term VADs in paediatric patients, focusing on successful bridging to transplant or recovery, alongside complications and waitlist mortality. By addressing this gap, we aim to inform clinical decision-making and optimize VAD strategies for paediatric heart transplant candidates.

Methods

Search strategy and data sources

A comprehensive search adhering to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [14] was conducted across various databases, including PubMed, EMBASE, CiNAHL, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Scopus, and Web of Science, from their inception to 2 December 2024. The search strategy was developed and executed by a qualified medical reference librarian in consultation with the principal investigator and included a combination of controlled vocabulary and keywords related to ventricular assist devices (VADs) and paediatric populations. The detailed search strategy is provided in Additional file 1. This study was prospectively registered with PROSPERO (CRD42023468125).

Eligibility criteria and quality assessment

Studies included in the analysis met specific inclusion criteria: (1) paediatric patients aged ≤ 18 undergoing temporary VAD placement as defined by PEDiMACs; (2) temporary VAD devices including percutaneous devices such as Impella (Abiomed), and TandemHeart (CardiacAssist), or surgical devices such as CentriMag (Thoratec), PediMag (Thoratec), BVS 5000 (Abiomed), Rotaflow (Maquet), Revolution (Sorin), which were devices PEDiMACs categorizes as 'temporary' or short-term VAD [15] reporting at least one of the primary outcomes of successful bridge to transplant, waitlist mortality, weaning off or remaining on support, and duration of support.

Exclusion criteria comprised case reports, case series, abstracts, review articles, studies with fewer than 5 patients, and articles not in English. Additionally, studies primarily focusing on medications, extracorporeal membrane oxygenation (ECMO), or other modalities were excluded from the meta-analysis. Screening and data extraction were independently performed twice from multiple assessors (LB, JB, JN, SM, SS, SZS) with disagreements resolved through discussion with co-authors and adjudication by NQEY.

The quality assessment of each study was conducted by two authors (LB and NQEY) using the Risk Of Bias In Non-randomized Studies - of Interventions (ROBINS-I) [16]. In cases of disparity, two independent assessors deliberated, and disagreements were settled through adjudication by CAT.

Extracted outcomes and definitions

Baseline (gender, weight, BMI, body surface area), clinical (diagnosis, INTERMACS or PediMACS profile, VAD type, pre-operative characteristics), and epidemiological (comorbidities) characteristics, as well as post-operative outcomes and complications directly related to the procedure itself were extracted. The primary outcomes included proportion of patients successfully bridged to heart transplant (n), waitlist mortality (n), number of patients weaned off (n) or remaining on support (n) and duration of support (days). Secondary outcomes included post-operative complications such as haemorrhage, renal impairment, cerebrovascular events, infection and thromboembolism.

Statistical analysis

The pooled means and proportions of this data set was analysed using a random-effects, generic inverse variance method of DerSimonian and Laird that assigns the weight of each study based on its variance [17]. Heterogeneity of effect size estimates across studies was assessed using the Q statistic and I^2, with significance set at $P < 0.10$. I^2 values were categorized as follows: 0–25% indicating insignificant statistical heterogeneity, 26–50% suggesting low heterogeneity, and 51–100% indicating high heterogeneity. Publication bias was visually assessed using a funnel plot for outcomes [18]. In cases where mean and standard deviation (SD) were unavailable, median values were converted to means using established formulas from the Cochrane Handbook for Systematic Reviews of Interventions [19]. Data analysis was performed using OpenMetaAnalyst software (Center for Evidence-Based Medicine (CEMB), Brown University, Providence, Rhode Island, USA).

Results

Study selection and patient characteristics

The initial search yielded 6952 relevant articles after duplicates were removed, from which 294 full texts were evaluated to result in 12 retrospective studies meeting the eligibility criteria. Details of the study selection process can be found in the PRISMA flowchart, as shown in Fig. 1. A total of 532 patients were included, with a reported mean age of 10.0 years (<0.1–18.3), mean weight of 39.5 ± 30.3 kg, and mean body surface area (BSA) of 1.4 ± 0.6 m^2. The baseline characteristics of the studies and their respective patients and devices can be found in Table 1.

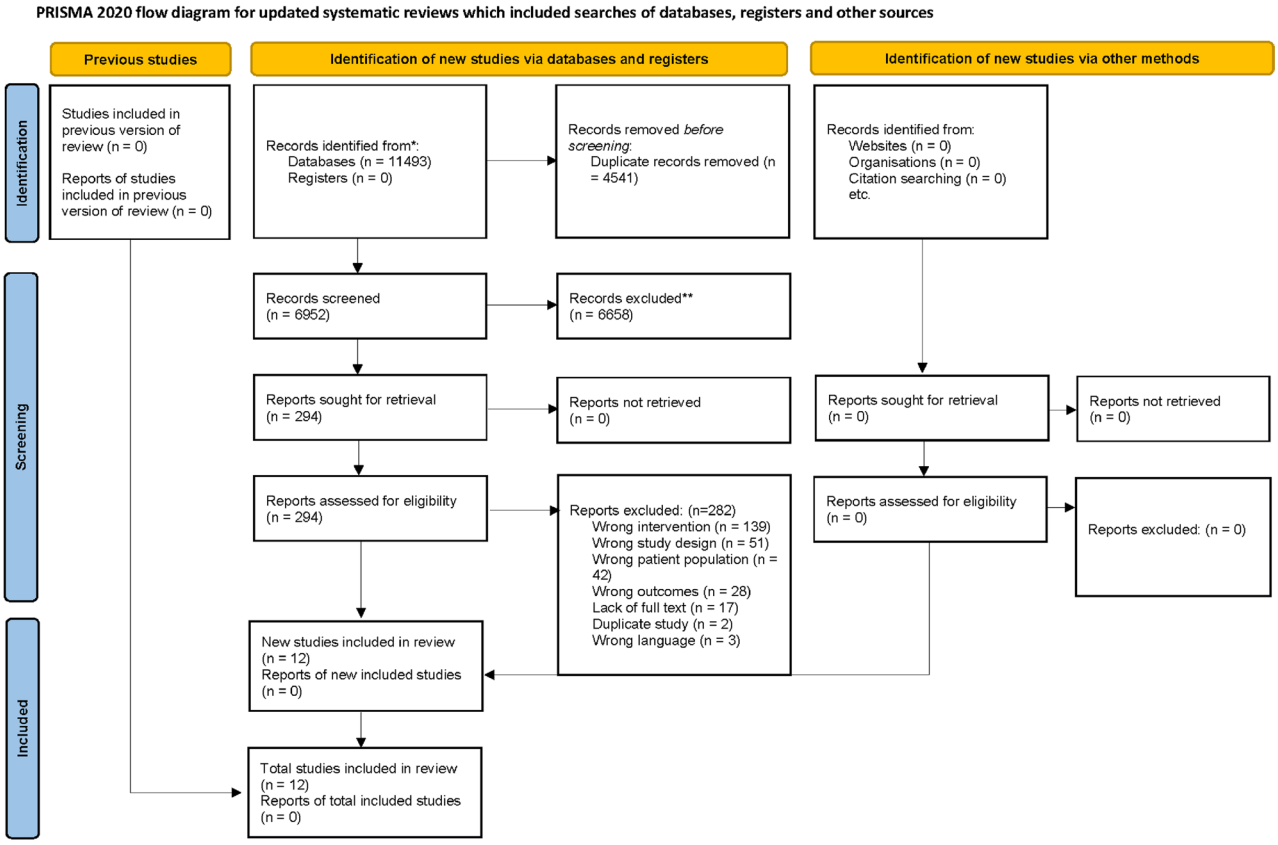

Fig. 1 Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flowchart

Table 1 Baseline and device characteristics of included studies

Study	Year	Country	Data collection years	Number of patients (N)	Number of male participants (N)	Mean age ± SD (years)	Mean weight ± SD (kg)	Mean body surface area ± SD (m^2)	Diagnosis	Type of Short-term VAD	Device flow type	Profile
Bearl et al.	2019	USA	2011 – 2016	13	6	2.7 ± 4.5	13.3 ± 18.1	NR	CHD (n=3)Cardiomyopathy (n=8) Myocarditis (n=2)	CentriMag, Thoratec (n=7)PediMag, Thoratec (n=6)	Continuous (n=13)	NR
Chen et al.	2012	USA	2000 – 2010	13	NR	7.9 ± 5.3	31.8 ± 22.5	NR	NR (n=13)	BVS 5000, Abiomed (n=2)CentriMag, Thoratec (n=10)PediMag, Thoratec (n=1)	Continuous (n=11) Pulsatile (n=2)	NR
Dipchand et al.	2018	Canada	1993 – 2015	140	NR	NR	NR	NR	NR (n=140)	BVS 5000, Abiomed (n=NR)CentriMag. Levitronix (n= NR)Tandem Heart, Cardiac Assist (n= NR)Rotaflow. Maquet (n= NR) Biomedicus, Medtronic (n= NR)	NR(n=140)	NR
Hill et al.	2006	USA	1982 – 2005	209	136	14.5 ± 3.3	57.0 ± 25.3	1.6 ± 0.4	CHD (n=11)Cardiomyopathy (n=104)Cardiac Arrest (n=7)Failure to wean from cardiopulmonary bypass Post-cardiotomy(n=9) Myocarditis (n=48)NR (n=20)Other (n=4)Post-transplantation heart failure (n=6)	CentriMag, Thoratec (n=209)	Continuous (n=209)	NR
Hsu et al.	2012	Taiwan	2008 – 2011	7	5	11.9 ± 2.5	49.7 ± 23.7	NR	CHD (n=1)Cardiomyopathy (n=6)	CentriMag. Levitronix (n=5)CentriMag, Thoratec (n=2)	Continuous (n=7)	NR
Levi et al.	2002	USA	1995 – 2001	8	NR	13.4 ± 3.3	45.5 ± 19.6	1.5 ± 0.5	CHD (n=1)Cardiomyopathy (n=5) Myocarditis (n=1)Muscular dystrophy (n=1)	BVS 5000, Abiomed (n=4)CentriMag, Thoratec (n=3)Biomedicus, Medtronic (n=1)	Continuous (n=4) Pulsatile (4)	NR
Lim et al.	2020	Korea	2000 – 2018	11	6	8.6 ± 4.2	26.9 ± 33.8	1.0 ± 0.5	Cardiomyopathy (n=5)Myocarditis (n=6)	Bio-pump, Medtronic (n=NR)Rotaflow. Maquet (n=NR)	Continuous (n=11)	NR
Lorts et al.	2018	USA	2012 – 2016	63	37	3.7 ± 4.6	16.0 ± 23.3	0.8 ± 0.6	CHD (n=26)Cardiomyopathy (n=25)Myocarditis/Transplant-Rejection (n=12)	Impella, Abiomed (n=NR)CentriMag/ PediMag, Abbott (n=NR)Tandem Heart, CardiacAssist (n=NR)Rotaflow. Maquet (n=NR)AB5000, Abiomed (n=NR)Revolution, Sorin (n=NR)	NR (n=63)	INTERMACS 1 (n=32) INTERMACS 2 (n=27) INTERMACS 3 (n=4)
Miana et al.	2018	Brazil	2012 – 2016	17	8	5.2 ± 2.6	16.0 ± 13.7	NR	CHD (n=2)Cardiomyopathy/Myocarditis (n=15)	CentriMag, Thoratec (n=NR)Rotaflow. Maquet (n=NR)	Continuous (n=18)	INTERMACS 2 (n=17)
Monge et al.	2016	USA	2011 – 2015	13	6	6.5 ± 3.9	21.0 ± 20.1	0.8 ± 0.4	CHD (n=3)Cardiomyopathy (n=8) Myocarditis (n=2)	Tandem Heart, Cardiac Assist (n=13)	Continuous (n=13)	NR

Table 1 (continued)

Study	Year	Country	Data collection years	Number of patients (N)	Number of male participants (N)	Mean age ± SD (years)	Mean weight ± SD (kg)	Mean body surface area ± SD (m^2)	Diagnosis	Type of Short-term VAD	Device flow type	Profile
Sughimoto et al.	2022	Canada	2005 – 2019	30	17	0.3 ± 1.5	5.3 ± 6.5	NR	CHD (n=17)Non-congenital Heart Disease (n=13)	CentriMag/PediMag, Abbott (n=NR) Rotaflow. Maquet (n=NR)	Continuous (n=30)	PediMACS 1 (n=27) NR (n=3)
Wilmot et al.	2011	USA	1995 – 2005	8	NR	8.1 ± 4.0	31.0 ± 22.6	NR	Myocarditis (n=8)	Tandem Heart, Cardiac Assist (n=1)Rotaflow. Maquet (n=1)Biomedicus, Medtronic (n=6)	Continuous (n=8)	NR

N Number of patients, *NR* Not reported, *SD* Standard deviation, *USA* United States of America, *CHD* Congenital Heart Disease, *IHD* Ischaemic Heart Disease, *NR* Not reportedBaseline and device characteristics of included studies

Risk of bias

All studies were observational with ROBINS-I utilized for judgement. A total of 16.7% (n = 2) were considered serious risk [20, 21], 41.7% (n = 5) were considered moderate risk [22–26] and 41.7% (n = 5) were low risk [15, 27–30]. The exposure and outcomes were appropriately measured, and the follow-up period was sufficient to observe any changes in clinical outcomes. Serious risk was noted in domains of confounding [20, 21] and of selection of participants [20, 21]. Results of the quality assessment can be found in Fig. 2.

Clinical characteristics

The studies that were included yielded a total of 532 patients, whose aetiology of heart failure included but was not limited to cardiomyopathy (44.9%), myocarditis (22.1%), CHD (17.9%), cardiac arrest (2.0%), and other (13.4%). The aetiology of 173 patients was not reported. The pooled proportion of each aetiology based on reporting studies are included in (Table 2).

The reported devices utilized in the studies included 85.3% CentriMag (Thoratec), 5.2% TandemHeart (CardiacAssist), 2.6% PediMag (Thoratec), 2.6% Biomedicus (Medtronic), 2.3% BVS 5000 (Abiomed), 1.9% Centrimag (Levitronix), and 0.4% Rotaflow (Maquet) with a further 261 included devices but with patient numbers (n) not reported (Table 3).

Device configurations included 51.4% LVAD support, 43.0% BiVAD support, 5.7% RVAD support, with 160/532 device configuration not reported. Pooled proportions of VAD device configuration are shown below (Table 4).

Pooled estimates of outcomes

All 12 studies reported the primary outcome following implantation, with the pooled proportions of patients successfully bridged to transplantation at 50.7% (95% CI 36.4%, 65.0%; I^2 = 91.1%, n = 532). Waitlist mortality while on device was estimated at 24.8% (95% CI 17.6%, 31.9%; I^2 = 63.8%, n = 532). 14.0% (95% CI 7.2%, 20.9%; I^2 = 87.52%, n = 532) of patients were weaned off VAD while 5.4% (95% CI 2.6%, 8.3%; I^2 = 39.1%, n = 532) of patients remained on VAD support [15, 20–30]. Mean duration of support on VAD was analysed in 11 studies and was 15.2 days (95% CI 9.9, 20.6, I2 = 83.4%, n = 392) [15, 21, 22, 24–32] (Fig. 3). The funnel plots of the primary outcomes can be found in Additional file 2.

Pooled estimates of outcomes sub-grouped by underlying diagnosis

In patients with CHD, pooled proportions of successful bridge to transplant was 49.3% (95% CI 15.6%, 83.0%; I^2 = 79.3%, n = 34), waitlist mortality was 42.5% (95% CI 15.4%, 69.6%; I^2 = 64.7%, n = 34), weaning off device was 20.0% (95% CI 7.4%, 32.7%; I^2 = 0%, n = 34) and

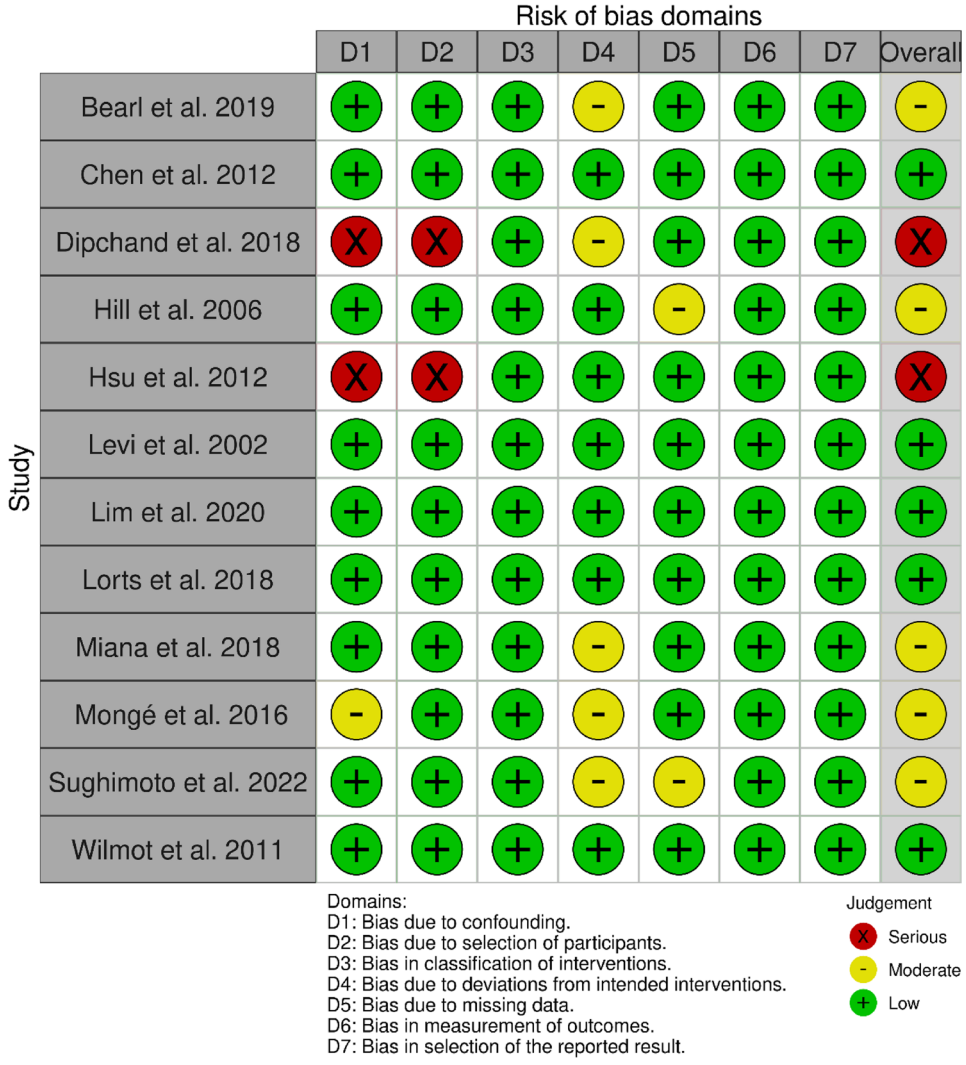

Fig. 2 Risk of bias in non-randomized studies of interventions (ROBINS-I) assessment

Table 2 Aetiology of patients requiring VAD in included studies

Aetiology	Proportion (%)	95% CI (%)	I^2 (%)	Included study groups (*n*)	Sample Size (*n*
Cardiomyopathy	49.3	33.9–64.7	83.7	8	332
Myocarditis	29.8	11.6–48.0	92.7	8	332
Congenital Heart disease	19.3	8.1–30.5	86.1	10	379
Cardiac arrest	2.1	0.6–3.6	0	8	341
Other					
Cardiomyopathy/Myocarditis	88.2	-	-	1	17
Non-congenital heart disease	43.3	-	-	1	30
Muscular dystrophy	12.5	-	-	1	8
Failure to wean from CPB Post-cardiotomy	4.3	-	-	1	209
Post-transplantation heart failure	2.9	-	-	1	209
Other Aetiology	1.9	-	-	1	209

CPB Cardiopulmonary bypass, *CI* Confidence Interval

Table 3 VAD devices of included studies

Device name	Manufacture	Included studies (*n*)	Studies (*n*) NR device numbers	Studies (*n*) reporting device numbers	Sample size (*n*) of included studies	Sample size (*n*) of NR studies	Sample size (*n*) of reported studies	Number of device (*n*) in reported studies
CentriMag	Thoratec	8	3	5	360	110	250	231
Rotaflow	Maquet	6	5	1	269	261	8	1
CentriMag	Levitronic	4	3	1	240	233	7	5
PediMag	Thoratec	4	2	2	119	93	26	7
TandemHeart	CardiacAssist	4	2	2	224	203	21	14
Biomedicus	Medtronic	3	1	2	156	140	16	7
BVS 5000	Abiomed	3	1	2	161	140	21	6
Impella	Abiomed	2	2	0	63	63	-	-
AB5000	Abiomed	2	2	0	203	203	-	-
Revolution	Sorin	1	1	0	63	63	-	-
Biopump	Medtronic	1	1	0	11	11	-	-
Overall		12	5	7	532	261		271

NR Not reported

Table 4 Pooled proportions of VAD device configuration

Study	Proportion (%)	95% CI (%)	I^2 (%)	Included studies (*n*)	Sample size (*n*)
LVAD	55.8	34.0–77.6	96.3	10	372
RVAD	5.5	1.6–9.5	52.8	10	372
BiVAD	36.3	12.5–60.1	97.7	10	372

LVAD Left ventricular assist device, *RVAD* Right ventricular assist device, *BiVAD* Bilateral ventricular assist device, *CI* Confidence Interval

remaining on support was 12.6% (95% CI 2.1%, 23.1%; I^2 = 0%, *n* = 34) [15, 21, 22, 25, 28] (Fig. 4).

In patients with cardiomyopathy, pooled proportions of successful bridge to transplant was 67.5% (95% CI 31.4%, 100%; I^2 = 91.8%, *n* = 52), waitlist mortality was 12.1% (95% CI 3.6%, 20.6%; I^2 = 0%, *n* = 52), weaning off device was 10.2% (95% CI 2.6%, 17.8%; I^2 = 0%, *n* = 52) and remaining on support was 15.2% (95% CI 0.4%, 30.0%; I^2 = 67.2%, *n* = 52) [15, 21, 22, 25, 28] (Fig. 5).

In patients with Myocarditis, pooled proportions of successful bridge to transplant was 16.9% (95% CI 3.1%, 30.8%; I^2 = 0%, *n* = 25), waitlist mortality was 20.0% (95% CI 5.2%, 34.7%; I^2 = 0%, *n* = 25), weaning off device was 56.3% (95% CI 37.4%, 75.1%; I^2 = 0%, *n* = 25) and remaining on support was 7.6% (95% CI 0%, 16.9%; I^2 = 0%, *n* = 25) [15, 22, 25, 28, 30] (Fig. 6). The Pooled estimates of outcomes by underlying diagnosis are represented below (see Fig. 7)

Complications

Complications were analysed, the most common being haemorrhage, renal impairment, cerebrovascular events, infection and thromboembolism. Six studies reported the rate of haemorrhage at 38.9% (95% CI 17.9%, 59.8%, I^2 = 88.1%, *n* = 62) [15, 22, 24–26, 29]. Renal impairment was 35.2% (95% CI 9.5%, 60.8%, I^2 = 82.6%, *n* = 23) across four studies [15, 21, 22, 24]. Cerebrovascular events, including ischaemic and haemorrhagic strokes, was 29.5% (95% CI 18.6%, 40.4%, I^2 = 53.1%, *n* = 47) across seven studies [15, 21, 22, 24–26, 29]. Infection rate while on VAD support was 17.8% (95% CI 6.2%, 29.4%, I^2 = 71.4%, *n* = 25) across six studies [15, 21, 22, 24, 25, 29]. Thromboembolism was 9.9% (95% CI 2.3%, 17.5%, I2 = 74.8%, n = 15) across seven studies [15, 21, 22, 24–26, 29]. Pooled proportions of complications after VAD implantation are shown below (Fig. 8).

Discussion

With the increasing use of VADs as a bridge to transplantation, their application in paediatric populations has become an important and evolving area of research. This systematic review and meta-analysis evaluated the safety and efficacy of short-term VAD support in children. On average, patients required support for 15.2 days before reaching a definitive outcome of transplantation, weaning, or death. Our study demonstrated that 50.7% of children were successfully bridged to transplant, with a mortality rate of 24.8%. Weaning from support was achieved in 14.0% of cases, and 5.4% remained on device support at study endpoints. However, the use of short-term VADs was associated with notable complication rates, including haemorrhage (38.9%), renal impairment (35.2%), cerebrovascular events (29.5%), infection (17.8%), and thromboembolism (9.9%). These findings contribute new evidence that reinforces existing literature on paediatric short-term VAD use. Given the vulnerability of this high-risk population, our analysis provides a foundation for future research aimed at identifying prognostic factors that may optimise outcomes in children requiring cardiac transplantation.

These outcomes are broadly consistent with major paediatric mechanical circulatory support registries,

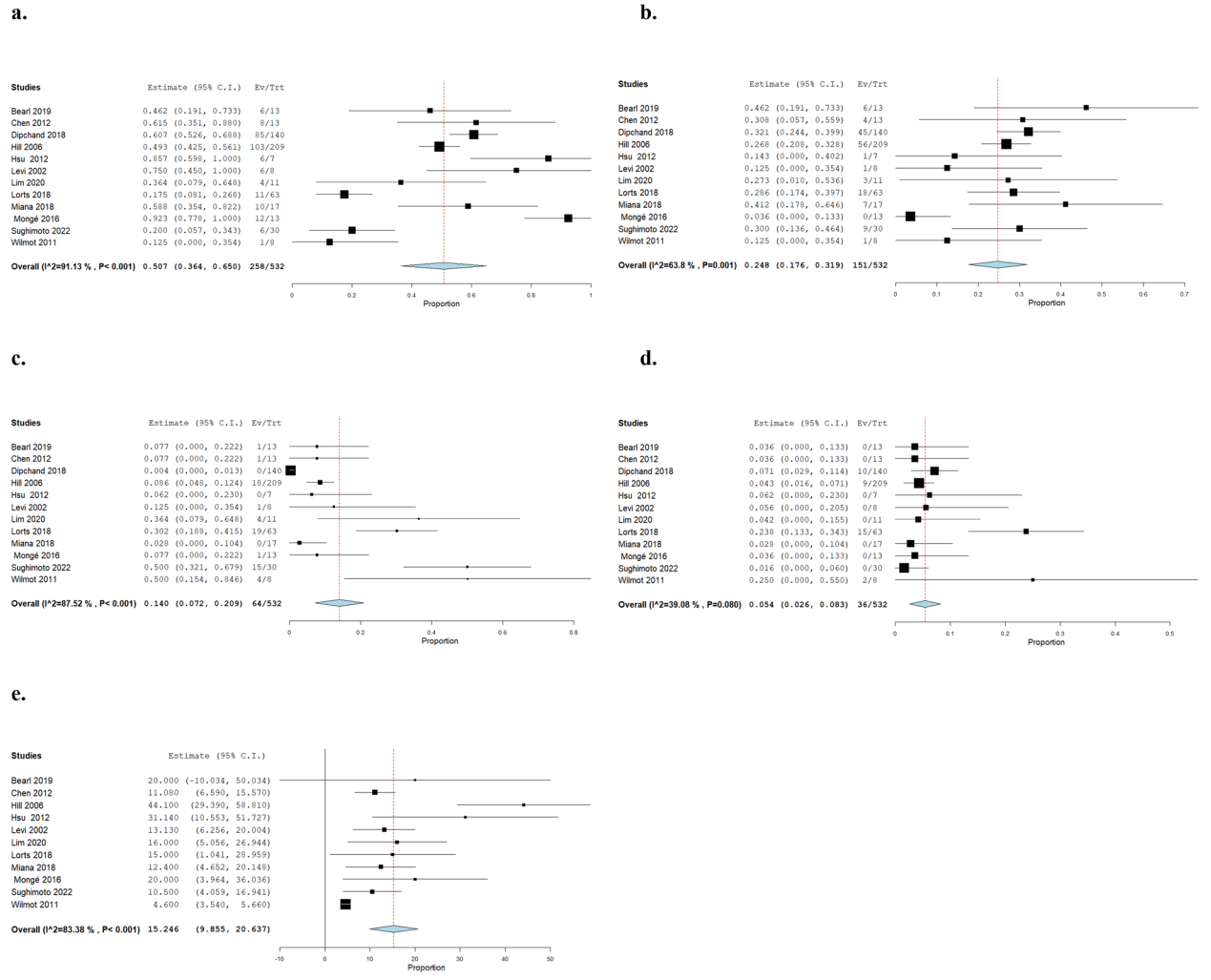

Fig. 3 Pooled estimates of outcomes following VAD implantation of all patients (**a**) bridged to heart transplantation, (**b**) Waitlist mortality on device (**c**) weaned off device (**d**) remaining on support (**e**) mean duration of support on device (days). *VAD* Ventricular assist device

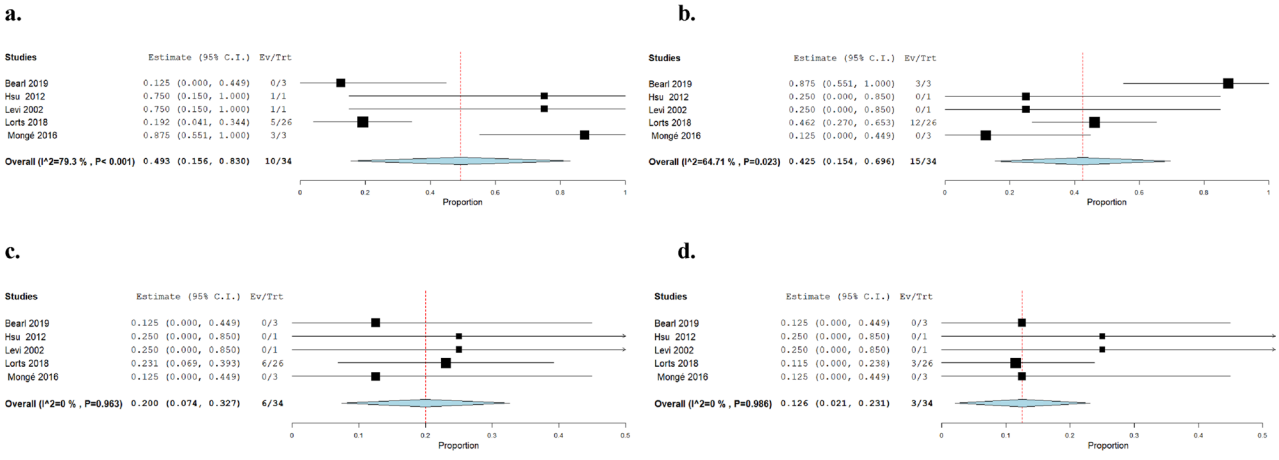

Fig. 4 Pooled estimates of outcomes following VAD implantation in patients with CHD (**a**) bridged to heart transplantation, (**b**) Waitlist mortality on device (**c**) weaned off device (**d**) remaining on support. *CHD* Congenital heart disease, *VAD* Ventricular assist device

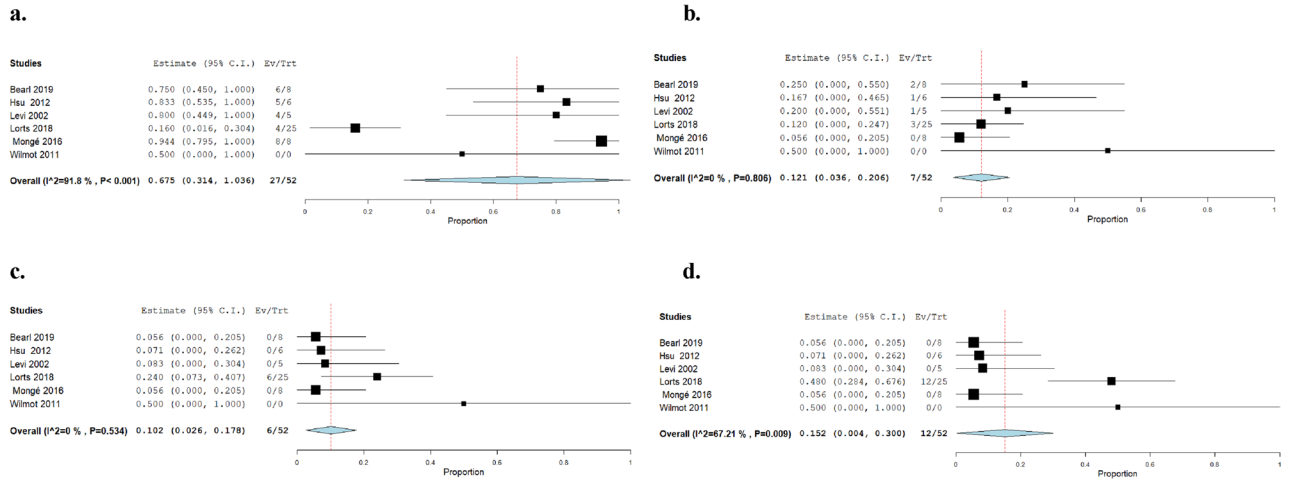

Fig. 5 Pooled estimates of outcomes following VAD implantation in patients with cardiomyopathy (**a**) bridged to heart transplantation, (**b**) waitlist mortality on device (**c**) weaned off device (**d**) remaining on support

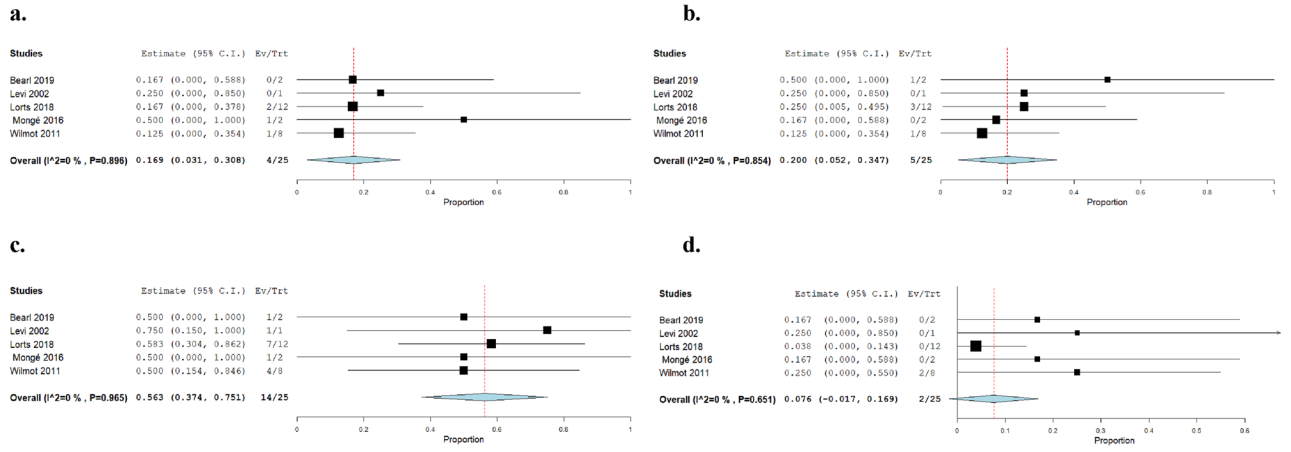

Fig. 6 Pooled estimates of outcomes following VAD implantation in patients with myocarditis (**a**) bridged to heart transplantation (**b**) waitlist mortality on device (**c**) weaned off device (**d**) remaining on support

including PediMACS and INTERMACS, while shedding light on the substantial burden of complications and heterogeneity in this vulnerable population. The bridge-to-transplant rate of 50.7% observed in our pooled analysis aligns with previously reported range of 50–57% at 6 months from the PediMACS registry [33] and INTERMACS registry for profile 1 and 2 paediatric patients [34]. Our meta-analysis identified a 24.8% waitlist mortality among patients receiving short-term VADs, which is higher than reported rates from PediMACS (19% from 2012 to 2017) and adult VAD-supported cohorts (17–20%) [35]. This figure remains substantially higher than the overall mortality reported for paediatric heart transplant candidates, regardless of mechanical support, that have been observed in more recent datasets. The United Network for Organ Sharing and the 2022 SRTR report overall waitlist mortality of approximately 10 patient deaths per 100 years and 13% mortality, respectively [1, 36]. This discrepancy is likely attributable to our inclusion of earlier patient cohorts supported with earlier iterations of devices. For example, 2011 SRTR database reported 20.8 patient deaths per 100 years among all paediatric heart transplant candidates where this decreased by more than half to 10.0 deaths per 100 patient-years in 2022 [1, 37]. Additionally, the elevated waitlist mortality observed in our study likely reflects the higher clinical acuity of children requiring VAD support, including a greater proportion with CHD, low body weight, or multi-organ dysfunction (such as renal impairment or thromboembolic events), factors consistently associated with increased waitlist mortality [1, 20, 34, 38, 39]. Notably, CHD patients have been reported to experience up to a four-fold higher mortality (36%) compared to those with cardiomyopathy (9%). This was supported in our study where pooled proportion showed a 42.5% waitlist mortality in CHD populations compared to 20.0% and 12.1% in myocarditis and cardiomyopathy populations.

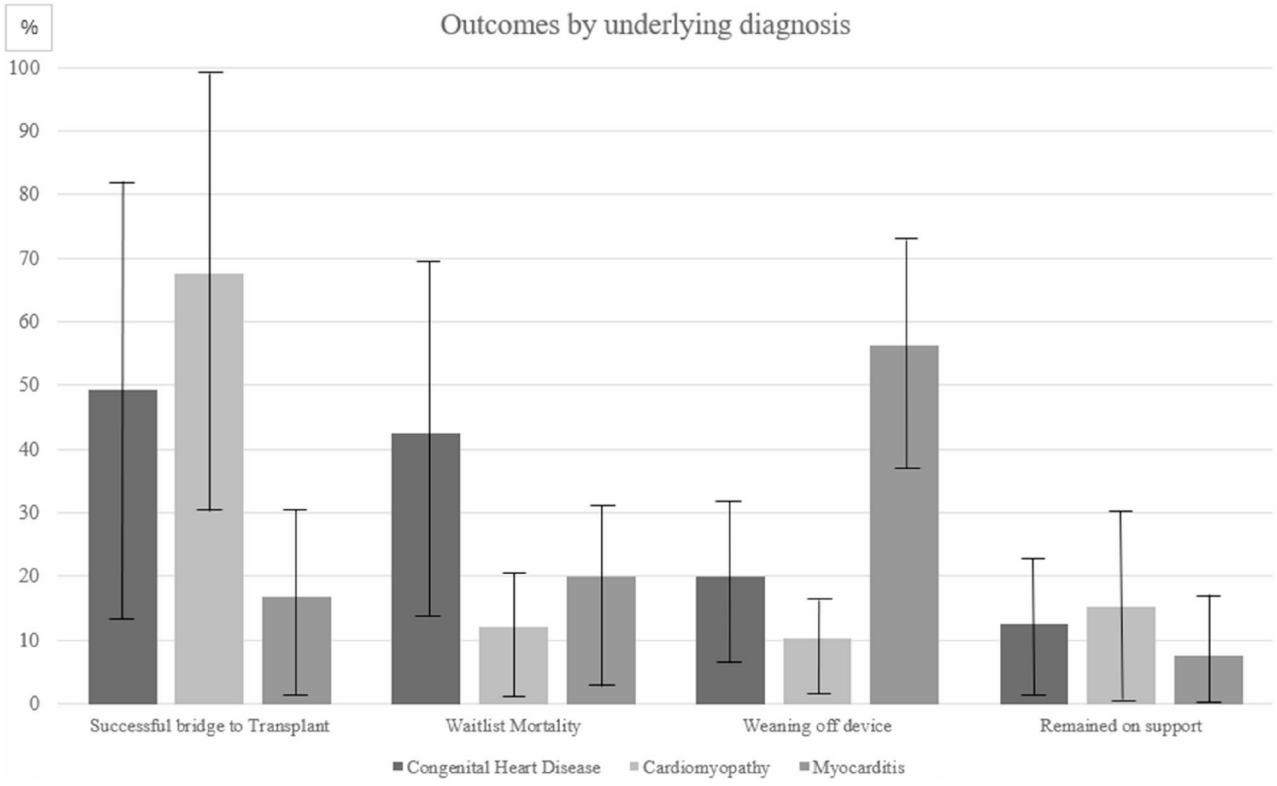

Fig. 7 Pooled estimates of outcomes sub-grouped by underlying diagnosis

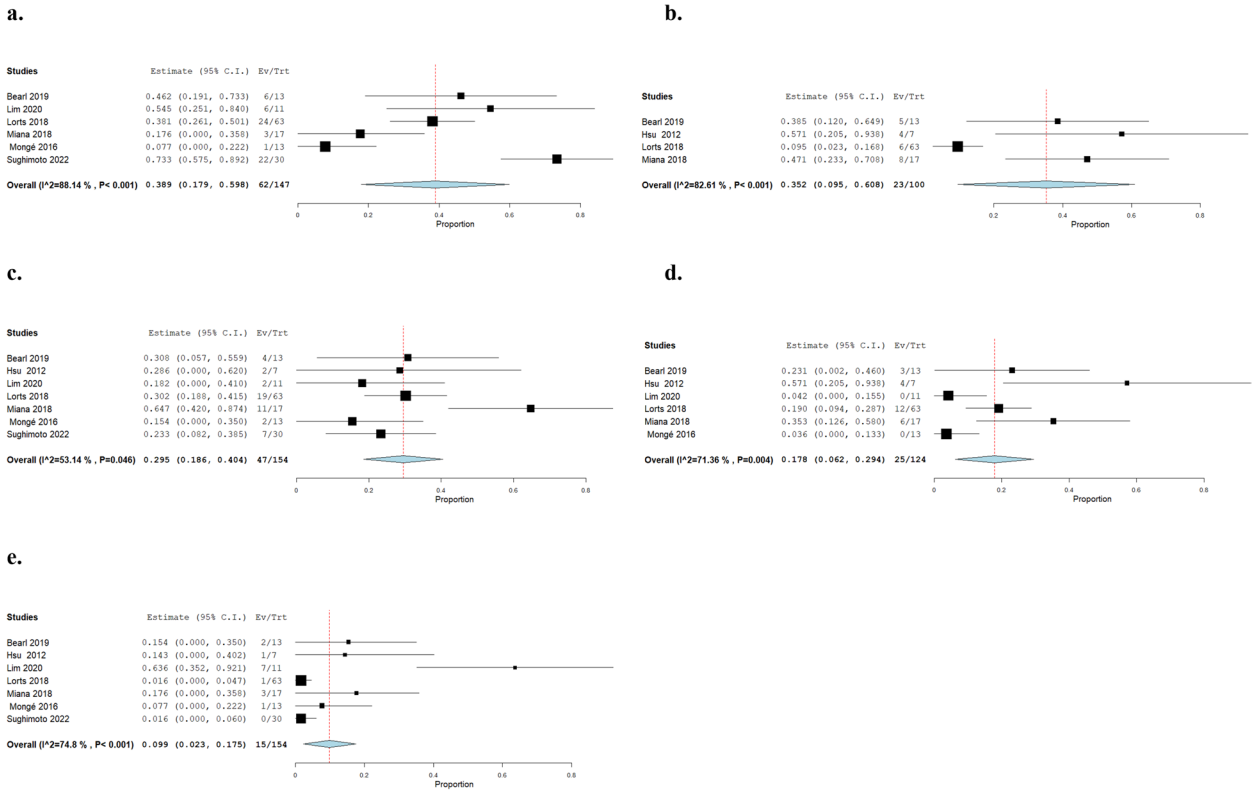

Fig. 8 Pooled estimates of proportions of complications after VAD implantation (**a**) haemorrhage, (**b**) renal impairment, (**c**) cerebrovascular events, (**d**) infection, (**e**) thromboembolism. VAD Ventricular assist device

Device-related factors also play a critical role in influencing patient outcomes. In our review, continuous-flow VADs, associated with improved survival and lower complication rates, comprised 98.2% of the reported cohort. In contrast, pulsatile-flow devices such as the earlier BVS 5000 (Abiomed) and Bio-Pump (Medtronic), which made up 1.8% of the sample, are typically used in infants and smaller children (< 20 kg) due to anatomical constraints limiting the applicability of continuous-flow systems. Prior studies support this distinction; for instance, pulsatile devices in INTERMACS profile 2 patients have been associated with significantly higher mortality (HR 3.9, 95% CI 1.6–9.5, $p = 0.003$) compared to continuous-flow VADs [34, 40]. Notably, percutaneous VAD devices, such as Impella, were reported in only two of the included studies and without reported numbers, reflecting that their role as a in paediatric patient is still emerging, where use have been limited to larger paediatric patients with suitable vascular access and isolated left ventricular dysfunction [15, 27]. Historically used off label, the recent 2024 U.S. Food and Drug Administration expansion of indication for Impella CP and Impella 5.5 in selected paediatric patients (≥ 52 kg and ≥ 30 kg respectively) is expected to increase utilisation in this growing subgroup [41]. These findings highlight the ongoing need for miniaturized continuous-flow devices for smaller children alongside percutaneous strategies matching adult durability and support while ensuring size-appropriate design and lower risk.

Another important consideration is the duration of support on outcomes of mortality and bridge to transplant [8]. In our meta-analysis, the mean support duration was 15.2 days. These relatively short durations reinforce the temporizing nature of short-term VADs, particularly in centres without routine access to long-term devices or where donor availability is limited. The high heterogeneity (I^2 =83.28%) observed in support duration likely reflects differences in patient selection, urgency of listing, institutional protocols, and regional differences in donor organ allocation policies.

A striking finding of this analysis is the high rate of complications. Haemorrhage was the most frequently reported event (37.7%), followed by cerebrovascular events (29.5%), renal impairment (29.7%), infection (17.8%), and thromboembolism (9.9%). These figures are consistent with prior paediatric studies and mirror adult VAD populations, where bleeding and cerebrovascular events and thromboembolism remain major causes of morbidity [41]. The balancing act of anticoagulation in especially in paediatric patients, makes managing these risks particularly complex. Device-specific thrombogenicity and variability in anticoagulation protocols contribute to this burden.

Interestingly, our review also suggests that the number of patients weaned from VADs (14.0%) and those still on support at the time of reporting (5.4%) were relatively low. This may reflect the limited capacity of short-term devices to facilitate myocardial recovery in paediatric heart failure, where the aetiology is often congenital and may be less reversible than in adult populations. In five studies, weaning off support in VAD population was 56% in myocarditis population, compared to 17.7% in CHD population. Nonetheless, the low weaning rates may also be a byproduct of centre practices prioritizing early transplant over recovery in children, or of limited data on recovery protocols in this population. Of those remaining on support, reporting was inconsistent whether these patients were transitioned to durable support or remained on temporary support. However, two articles do highlight a bridge-to-durable support before transplantation, waitlist mortality or weaning off support [15, 30]. For consistency in pooled analysis and to maintain a clear distinction between the outcomes of temporary and durable VADs, these was considered as remaining on support. This subgroup, nevertheless, does represent an important clinical trajectory that warrants more consistent reporting in context of intent of durable support.

This study has several important limitations that should be acknowledged. First, all included studies were retrospective in design, inherently subject to selection bias, reporting bias, and inconsistencies in data collection. The absence of randomized controlled trials or prospective cohort studies limits the ability to infer causality. Second, there was significant heterogeneity in patient populations, including variations in age, weight, underlying diagnoses (e.g., CHD vs. cardiomyopathy), prior utilisation of ECMO and severity of illness at the time of VAD implantation, which limited stratification according to aetiology or clinical acuity. This clinical heterogeneity likely contributed to the high I^2 values observed across most pooled estimates, reducing the precision of our effect sizes. Third, device types varied across studies, with a mix of pulsatile and continuous-flow systems used in different clinical contexts and age groups, limiting comparability. In addition, anticoagulation protocols and management strategies for complications were not standardized or consistently reported, which may have influenced complication rates and outcomes such as stroke or haemorrhage. Fourth, outcome definitions were not uniform, particularly for adverse events like infection, thromboembolism, or bleeding, and several studies lacked detailed information on whether events occurred on or off device, before or after transplant, or in the context of multi-organ dysfunction. Only a small subset of studies reported the timing or causes of death, or follow-up beyond the transplant or VAD explantation period, limiting insights into long-term survival, quality of life,

or neurological sequelae. Fifth, the meta-analysis does not fully account for center-level or geographic variations in VAD availability, transplant listing practices, or donor organ access, all of which may significantly influence outcomes but were not quantifiable in our analysis. Finally, the included studies span more than two decades during which device technology, patient selection and perioperative care have improved considerably. These advances, associated with better survival and complication rates, were not adequately stratified in the included studies and therefore may not be fully represented in the results.

Despite these limitations, a major strength of this meta-analysis is its specific focus on short-term VADs in the paediatric population, a subgroup often combined with long-term device cohorts in previous studies. This targeted approach allowed us to identify and quantify risks uniquely associated with short-term support, including elevated early complication rates and shorter time to transplant. Furthermore, our findings complement and extend existing registry data by providing additional granularity and emphasizing the need for standardized reporting of paediatric VAD outcomes, including complications, recovery, and long-term survival. As a next step, comparative analyses incorporating long-term VAD cohorts are warranted to contextualize these short-term outcomes within the broader landscape of mechanical circulatory support, and to better inform device selection, timing, and long-term prognostication.

Conclusions

This review represents an up-to-date synthesis of short-term VADs as a bridge to transplantation or recovery in paediatric patients. Short-term VADs demonstrate a bridge-to-transplant success rate of 50.7%, with a waitlist mortality of 24.8%, that align with major registries like PediMACS and INTERMACS. While short-term VAD remain a critical intervention for suitable candidates, these findings, including a high incidence of complication, underscore that they are not a universal solution and some populations still experience persistent challenges. Despite limitations such as heterogeneity in patient populations and device types, this analysis encapsulates the current state of paediatric short-term VAD literature. It provides a foundation for future studies to refine patient selection, optimise device design and standardize complication, ultimately aiming to enhance outcomes and reduce mortality in this vulnerable population.

Abbreviations

CHD	Congenital heart disease
ECMO	Extracorporeal membrane oxygenation
HTX	Heart transplant
INTERMACS	Interagency registry for mechanically assisted circulatory support
PediMACs	Pediatric Interagency Registry for Mechanically Assisted Circulatory Support
SRTR	Scientific registry of transplant recipients
VAD	Ventricular assist devices

Supplementary Information

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Additional file 1. Actual Search Strategies (word document).

Additional file 2. Funnel plots of primary outcomes following VAD implantation of all patients **a**) bridged to heart transplantation, **b**) waitlist mortality on device **c**) weaned off device **d**) remaining on support. *VAD* Ventricular assist device.

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Authors' contributions

Systematic review conception: CAT, SMScreening: AF, JN, LB, NQEY, SM, SZS. Extraction: AF, JN, LB, MLN, NQEY, OASO, SM, SZS. Statistical analyses: NQEY, SM. Drafted manuscript: CAT, NQEY, SM, SS, JWFB. Editing and final approval: All.

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Data availability

With publication, the data set used for this meta-analysis will be shared upon request from the study authors.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Cambridge University Hospitals NHS Foundation Trust, Addenbrookes Hospital, Cambridge CB2 0QQ, UK
[2]Baim Institute for Clinical Research, 930W Commonwealth Ave, Boston, MA 02215, USA
[3]Blackpool Victoria Teaching Hospital, Whinney Heys Rd, Blackpool FY3 8NR, UK
[4]University of Nicosia Medical School, Nicholas St 93, Egkomi, Nicosia 2408, Cyprus
[5]Faculty of Medicine, University of Queensland, Herston 4006, Australia
[6]Queensland Health Department, Mackay Base Hospital, Mackay 4740, Australia
[7]Division of Experimental Medicine, McGill University Montreal, Quebec, Canada
[8]Department of Internal Medicine, University of Connecticut, Farmington, CT 06269, USA
[9]Oxford University Hospitals NHS Foundation Trust, John Radcliffe Hospital, Headley Way, Headington, Oxford OX3 9DU, UK
[10]School of Biomedical Sciences, University of Queensland, St Lucia, Brisbane 4072, Australia
[11]Bolton NHS Foundation Trust, Minerva Road, Farnworth, Bolton BL4 0JR, UK

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